IX. *Experiments upon the Resistance of the Air.* *By* Richard Lovell Edgworth, *Esq. F. R. S.* *In a Letter to Sir* Joseph Banks, *Bart. P. R. S.*

Read January 16, 1782.

DEAR SIR,

Edgeworth's Town, Ireland,
May 2, 1782.

THE laft time I had the pleafure of feeing you, the converfation turned upon the refiftance of the air, and upon a fingular experiment related by Mr. ROBINS in his Treatife upon Gunnery. I have fince repeated his experiment, and tried fome others, which I beg you to lay before the Royal Society, if you think them worthy their attention.

I have the honour to be, &c.

MANY experiments have been tried to afcertain the force and velocity of the wind, with a view to the conftruction and management of different engines, and more particularly for the purpofes of navigation. Several machines, which have been employed in thefe enquiries, are defcribed in the Tranfactions of the Royal Society, and in the Memoirs of Foreign Academies ; but the moft accurate which I have feen was invented by the late Sir CHARLES KNOWLES ; and from a number of experiments made with it, he had conftructed tables, fhewing at one view the force of the wind upon each fail of a fhip at every degree of velocity from one to ninety miles an hour.

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But thefe calculations, and many more of a fimilar nature, that are to be met with in BELIDOR's Architecture Hydraulique, and other books, are founded upon a fuppofition that the effect of the wind is directly as the furface upon which it acts. If, for inftance, its force be eftimated as one upon one fquare yard, its force upon two fquare yards fhould be eftimated as two, upon three fquare yards as three, &c.; but in fact this proportion is not to be depended upon, nor muft the refiftance of furfaces be eftimated merely by their extent; but feveral other circum-ftances muft be taken into confideration.

No figures can refemble each other more than a parallelo-gram and a fquare having the fame fuperficial contents, as they are both bounded by four ftraight lines meeting at right angles, yet they oppofe different degrees of refiftance to the air.

If two fimilar cards, for inftance, are placed oppofite the wind, one upon its end, and the other on its fide, and both inclined to the fame angle, the wind will have the greater effect upon the card that is placed end-ways.

To determine the difference of refiftance between thefe two furfaces, and to afcertain the effect of other figures moving through the air, I tried the following experiments. The two firft are to be found in Mr. ROBINS's Treatife upon Gunnery; but I thought it proper to repeat them, that they might be more readily compared with others made with the fame appa-ratus, efpecially as Mr. ROBINS made ufe of a machine con-ftructed upon a fmaller fcale than mine, and turning upon fric-tion wheels, which are not proper for machines of this nature, nor indeed for any purpofe, where an uniform motion is required.

Having faftened a ftrong joift of wood from one fide of a large room to the other, fo as to form a kind of bridge at fome diftance from the floor, I erected a perpendicular fhaft or roller, which turned freely in brafs fockets fixed into the floor and bridge upon pivots of hardened fteel one-fixteenth of an inch in diameter. On each fide of this roller was extended an arm of deal, feather-edged, and fupported by ftays of the fame material, feathered in the fame manner, to oppofe as little furface as poffible to the air when in motion.

Round the upper part of this roller was wound a ftring of cat-gut, which, paffing over pullies properly difpofed, was faftened to a fcale that defcended into the well of an adjoining ftair-cafe.

The extremity of thefe arms defcribed a fpace of more than forty feet in every revolution, the weight defcending in the fame time only fix inches. The time in all the following ex- periments was the fame; and, as each revolution was per- formed in four feconds, the velocity of the end of the arm on which the furface was fixed, was at the rate of about feven miles an hour.

The firft figure that I tried was a parallelogram of tin, nine inches long, and four inches wide. Its longeft fide was placed parallel to the floor, at the extremity of one of the arms. Its fhorteft fides were inclined to an angle of forty-five degrees from the perpendicular, and in this fituation it was carried round with its furface againft the air.

After fuffering it to revolve until I was fatisfied that its mo- tion was become uniform, I put as much weight into the fcale as moved it with a velocity of five turns in twenty feconds. I then changed the fituation of the parallelogram, placing its fhorteft fides parallel to the floor, and inclined to the fame

3   angle

angle as before. I now found, that more weight was required to produce the same velocity, though the quantity of surface was the same as in the preceding experiment. The weight necessary to put the machine alone in motion, with the velocity above mentioned, was two pounds and a half. When it car-ried the parallelogram with one of its shortest sides downwards, it required four pounds and a half additional weight; and when the parallelogram was reversed, another half pound was barely sufficient to give it the same velocity.

The difference, therefore, occasioned by placing the same pa-rallelogram with its longer or shorter sides inclined from the direction of its motion was equal to one-tenth of the greatest resistance.

It has been observed, that in these two experiments the mean velocity of the plane was not the same, as its extremity extended farther from the center of the machine in one than in the other. This is strictly true; but the size of the parallelo-gram bore so small a proportion to the length of the radius to which it was fastened, that the error arising from this circum-stance is scarcely perceptible, and the advantage being in favour of that which required the least weight, I did not think it necessary to bring it into account.

Having formed a general idea of the reason of the difference in these experiments, it occurred to me, that there would be a greater disproportion between the resistance of some other figures, which Mr. ROBINS had not tried; and having put a rhomboid, in the form of a lozenge, nine inches long, and four broad, in the place of the parallelogram, the difference was increased from one-tenth to one-seventh of the weight employed to give them the required velocity.

<div align="center">T 2</div>

<div align="right">Pursuing</div>

Purfuing the fame reafoning that led me to the laft experi-
ment, it occurred to me, that even againft figures of exactly
the fame fhape, the refiftance of the air, when the dimenfions
of the figures were enlarged, would not be increafed in the
fame proportion as the fize of the planes, but in a much higher
ratio; and that, by bending the planes as a fail, the refiftance
would be ftill farther increafed, though the fection of air, that
would be intercepted by the planes, muft by thefe means be
confiderably leffened.

The refult far furpaffed my expectations. A fquare of tin,
containing fixteen fquare inches, placed perpendicularly, was
refifted as two and a half. A fquare, containing fixty-four
inches, or four times the former quantity, inftead of meeting
with a refiftance as ten or four times the former refiftance,
required no lefs than fourteen pounds to give it the fame
velocity.

Four-tenths (or nearly half as much again) was an increafe
of refiftance that made me fufpect fome error in the experiment;
but having repeated it feveral times with great care, and having
examined all the parts of the machine, I was fatisfied that I
had made no miftake.

I now placed the parallelogram of nine inches long upon
the arms of the machine, with its fhorteft fides parallel to the
horizon, bending it to fuch an arch that its chord meafured
eight inches, and inclining it to an angle of forty-five degrees.
And though the fection of air that it intercepted was by thefe
means diminifhed one-ninth, yet the refiftance was increafed
from five to five and a half. And when the parallelogram
was bent yet farther, and its chord contracted almoft to feven
inches, the refiftance was increafed to five and three-quarters.

I mention thefe numbers in grofs to avoid confufion; but in
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the table at the end of this paper, the meaſures and weights are ſet down exactly.

Dr. HOOK, whoſe name muſt be reſpected by every experimental philoſopher, was aware, that although he thought he could demonſtrate that flat ſails were preferable to ſuch as were curved and hollowed by the wind, yet until proper experiments had been tried, nothing could be poſitively determined.

He ſays ſomewhere in his poſthumous works, " That he " was ſurpriſed at the obſtinacy of ſeamen, in continuing, " after what appeared the cleareſt demonſtration to the con- " trary, to prefer bellying or bunting ſails to ſuch as were " hauled taught; but that he would, at ſome future time, " add the teſt of experiment to mathematical inveſtigation." He reaſoned upon a ſuppoſition, that the air in motion followed the ſame laws as light; and that it was reflected from ſurfaces with the angle of reflection equal to the angle of incidence, which is not the caſe, as it never makes an angle with the plane, but is always reflected in curves. Monſ. PARENT, and other mathematicians, have fallen into the ſame miſtake. No demonſtration of this ſort was more commonly known or received among practical mechanics, than that the beſt angle for the ſails of a wind-mill, at the beginning of their motion, was an angle of forty-five degrees; and that the maximum of an under-ſhot water-wheel was when it moved with one-third of the velocity of the water: but Mr. SMEATON, in an excellent paper in the Philoſophical Tranſactions, has refuted this opinion by the cleareſt experiments.

I had intended to diverſify theſe experiments, and to extend them to a more intereſting ſubject of enquiry, to determine the beſt ſhape of ſails, and the angle to which they ſhould be ſet, to obtain the greateſt progreſſive effect with the leaſt lee-

way ;

way; but, as a more complicated apparatus than I could at present procure is neceffary for this purpofe, I determined to offer you the flight progrefs I have made, in hopes that fome gentleman, more converfant and more interefted than myfelf in thefe inquiries, may purfue them with fuccefs and advantage to the public. I fhall only remark, that the general caufe of the different refiftance of the air upon furfaces of different fhapes, is the ftagnation of that fluid near the middle of the plane upon which it ftrikes. The fhape and fize of the portion thus ftagnated, differs from the fhape and angle of the plane. The elafticity of the air permits the parts in motion to comprefs thofe which are firft ftopped or retarded by the plane, and forms, as it were, a new furface of a different fhape, for the reception of thofe particles which fucceed. With the affiftance of a good folar microfcope the curves of the air ftriking againft different furfaces may be delineated, and when the general facts are once clearly afcertained, mathematicians will have an ample field for curious and ufeful fpeculation.

T A B L E.

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	Turns.	Time.	Weight.	
Machine alone - -	5	4	2	8
With a parallelogram of nine inches long and four broad, one of its longeft fides, parallel to the horizon and the parallelogram, inclined to an angle of 45°, -	5	4	7	0
Ditto, with one of its fhorteft fides downwards, - - -	5	4	7	9
With a lozenge nine inches long and four broad, with its longeft fide parallel to the horizon, - - -	5	4	5	8
Ditto reverfed, - - -	5	4	6	0
With a fquare piece of tin, four inches by four inches, - - -	5	4	5	0
Ditto, eight inches by eight inches,	5	4	16	6
With the former parallelogram, placed with one of its fhorteft fides downwards, inclined to an angle of 45°, and bent into an arch whofe chord was eight inches long, - - -	5	4	8	0
Ditto bent to an arch, the chord of which was feven inches and a quarter,	5	4	8	5